ENNING FUSION EXPERIMENT – ION (PFX-I)

Karl R. Umstadter*, Martin M. Schauer, Daniel C. Barn

Los Alamos National Laboratory Los Alamos, NM 87545

ICC Workshop

February 2000

Thanks to L. Chacón de la Rosa, M. H. Holzscheiter, F. L. Ribe, L. S. Schrank, R. A. Nebel, J. M. Finn,



Outline

Physics of Penning Fusion

Experimental Approach

Diagnostics

Latest Results

Summary

PF -- Motivation & Definition

- Pure electron plasmas may be well confined in crusized systems ($\tau = \text{hours} \Rightarrow \text{months}$)
- Density limited by Brillouin (B) and electrostatic stress (E)
- Use electron space charge to confine thermonucle ions
- Spherical ion focus to produce high power density
- Need 100 kV, cm radius, modest B



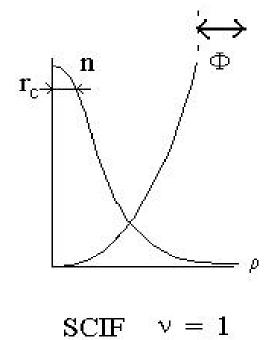
Small is Beautiful!

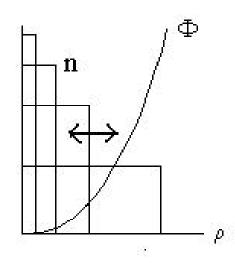
$$< n > \sim V_o / a^2$$
 $< n^2 > \sim < n >^2 \frac{a}{r_c}$
 $Power$
 $goes$
 $P \sim \frac{f(V)}{a} \frac{a}{r_c}$
 $egoes$
 $goes$
 $goes$
 $egoes$
 $egoes$

Ion Physics Theory Progress

- •Multiple Wells -- Miley ...
- •Maxwellian Component in Well ---Chacón ...
- •POPS -- Barnes, ...

Two Convergence Modes





 $POPS \quad v = 2$

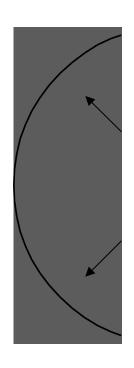
and the same of th

Ion Physics - POPS

Iniform n_e forms harmonic ion well aussian ion cloud stably oscillates thout damping from ion-ion llisions

eriodic focus gives high power nsity

eep well allows D-D operation





Electron Requirements

lectron confinement must be excellent

- Thermonuclear electron energy \Rightarrow v_e ~ c
- Electron density $\sim 10^{12}$ cm⁻³ for reactivity

Goal:

- Produce uniform n_e
- Electrostatic boundary conditions so that $\Phi_{\rm sc}$ is spherical

Conceptual Approach:

- Axial electrostatic electron well (end cathodes, central ano
- Magnetic insulation of anode
- Shaping of B field near anode to give uniform n

Electron Requirements (Cont.)

Uniform density requires nonthermal electron distribution

- Consider density along axis of symmetry
- No magnetic contribution, only electrostatic

$$n_o = n_a \exp(-e W/k_B T_e)$$

$$n_0$$
 n_a ? $k_B T_e >> e W$

- Electrostatic electron confinement requires applied voltage $V_o >> k_B T_e /e$
- Very inefficient use of V_o



100(s) kV in cm System

- Form electron beam in gun
 - Transport beam along B to electrically charge confinement region
- Confinement region consists of high-stress dielectrics or (preferably) only conductors
- Electrons reflected from second cathode (usually passive cathode)
- Reflexing beam builds large space charge from lo to modest beam current



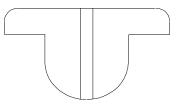
Experimental Approach

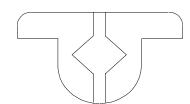
- Determine electron distribution in simple anode geometry
- Design field shaping with measured distribution
- Measure n_e by space charge **E** diagnostic

electrostatic shaping

Electrostatic shaping only

Electrostatic and magnetic shaping





Experimental Setup

SHOW SLIDES OF DIAGRAM (CAD) AND PICTURES OF TRAP

Diagnostic Equipment

- Monochrometer & Photomultiplier Tube
- Optics in Trap
- Fiber Optic Delivery of Light
- \Rightarrow Light is split 50/50

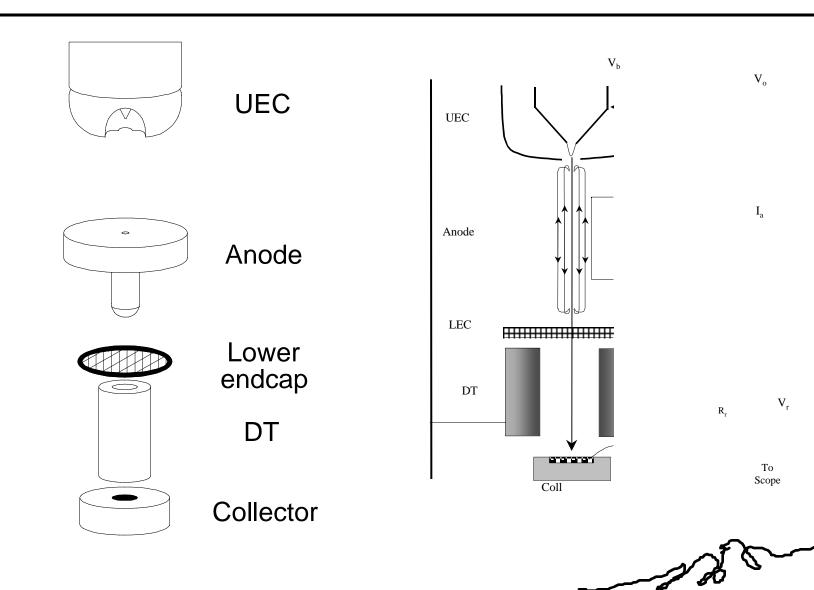
50%: to spectrometer for Stark measurement ne

50%: to PMT for photon counting ni

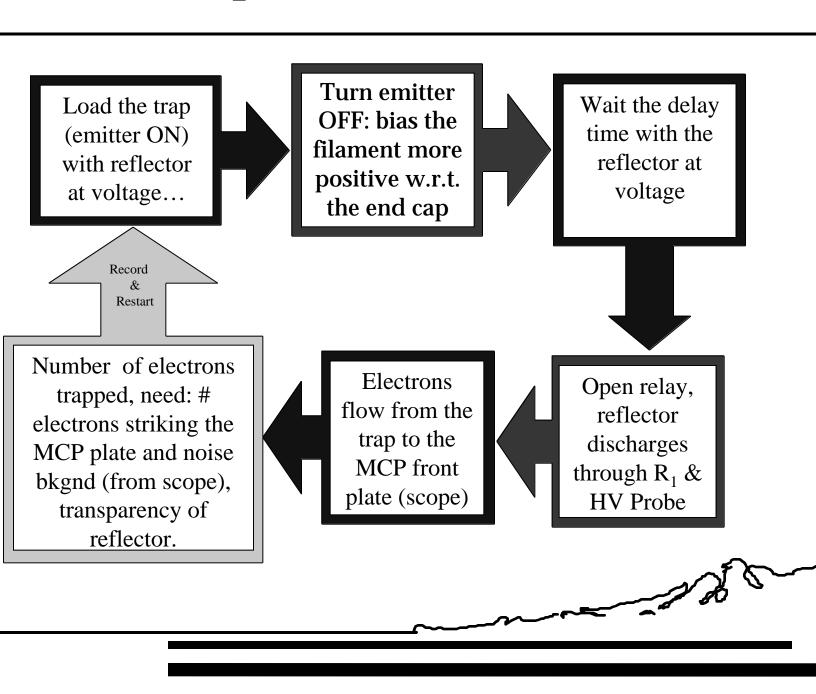
- Silicon Barrier Detectors ions/atoms lost from trap
- µChannel Plate Destructive detection of Ne



PFX-I Low-Voltage Electron Operation

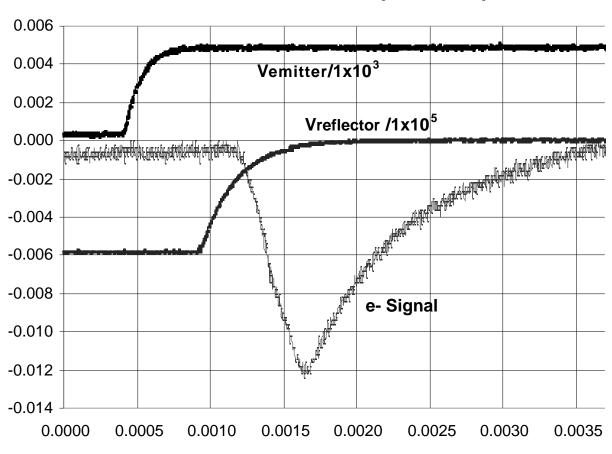


Experimental Procedure



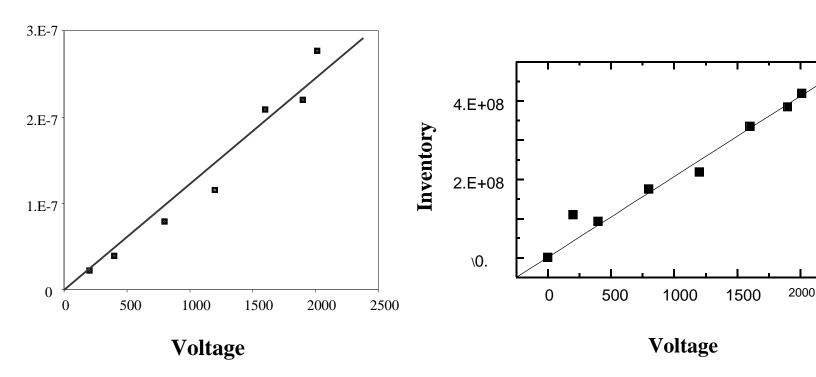
Electron Capture Example

Electron Capture - Exp 1



Time (sec)

Electron Trapping in PFX-I

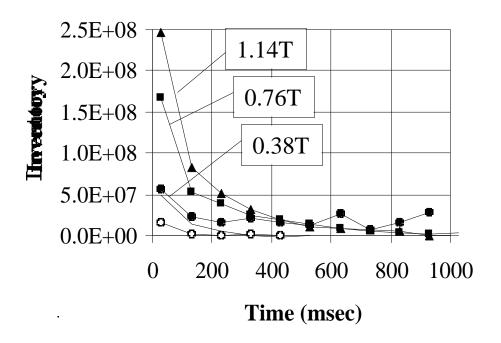


Electron inventory *vs.* time shows linear scaling with V

Anode Current *vs.* time shows linear scaling with V

independent of V

Electron Trapping in PFX-I



space-charge limit, then inventory should be independent of B Early time (30 ms) data shows B dependence

Electron Transport Models for PFX-I

Decay rate independent of inventory

$$N(t) = N_0 e^{-t/\tau_0}$$

Decay rate proportional to inventory

$$N(t) = \frac{N_o}{1 + t/\tau_o}$$



Application to PFX-I

Measure I_A , N_{30} , calculate N_o , o

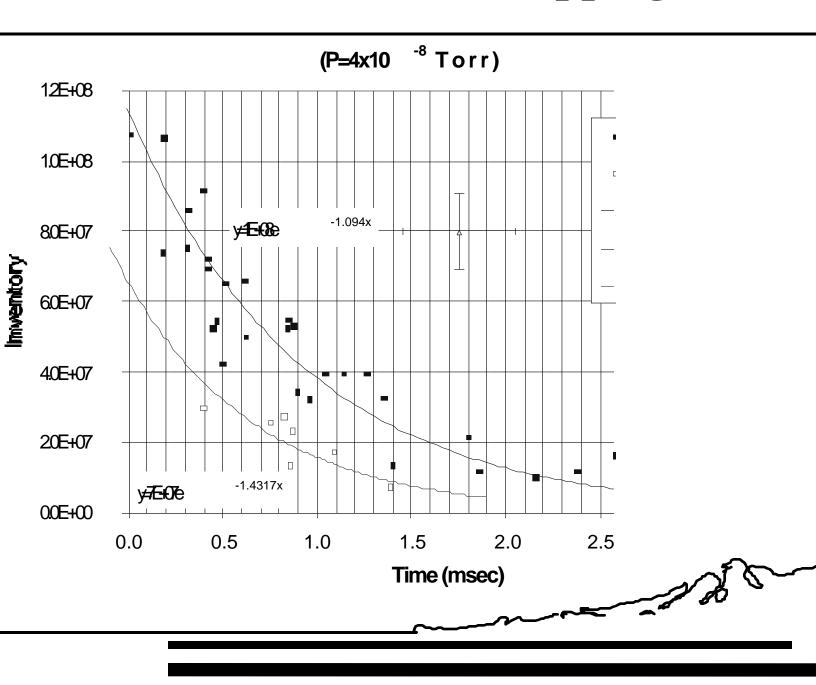
$$N(t) = N_{o} e^{-t/\tau_{o}}$$

	$N_{30}(10^8)$	$N_{0}(10^{8})$	o(ms)		
	1.14	30.7	9.11		
	4.19	21.2	18.5		
	6.17	23.3	22.6		

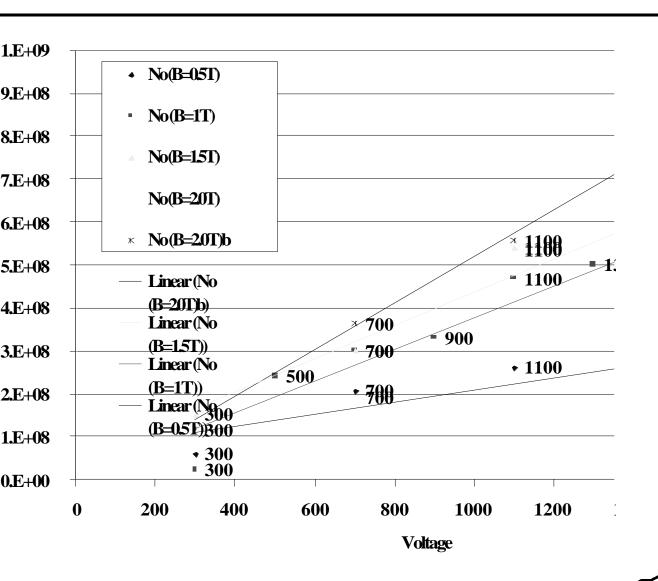
Phase II Experimental Setup



PFXI Electron Trapping



Phase II Experimental Results



Transport Mysteries

Adding any measurable amount of gas reduces confinement

Electron-neutral collision time is a few ms's

Thus, electrons must be lost in single collision. How can this happen with strong B?

Some ideas are large field errors + collisions (banana transport), collisions with trapped ions



Nondestructive Evaluation

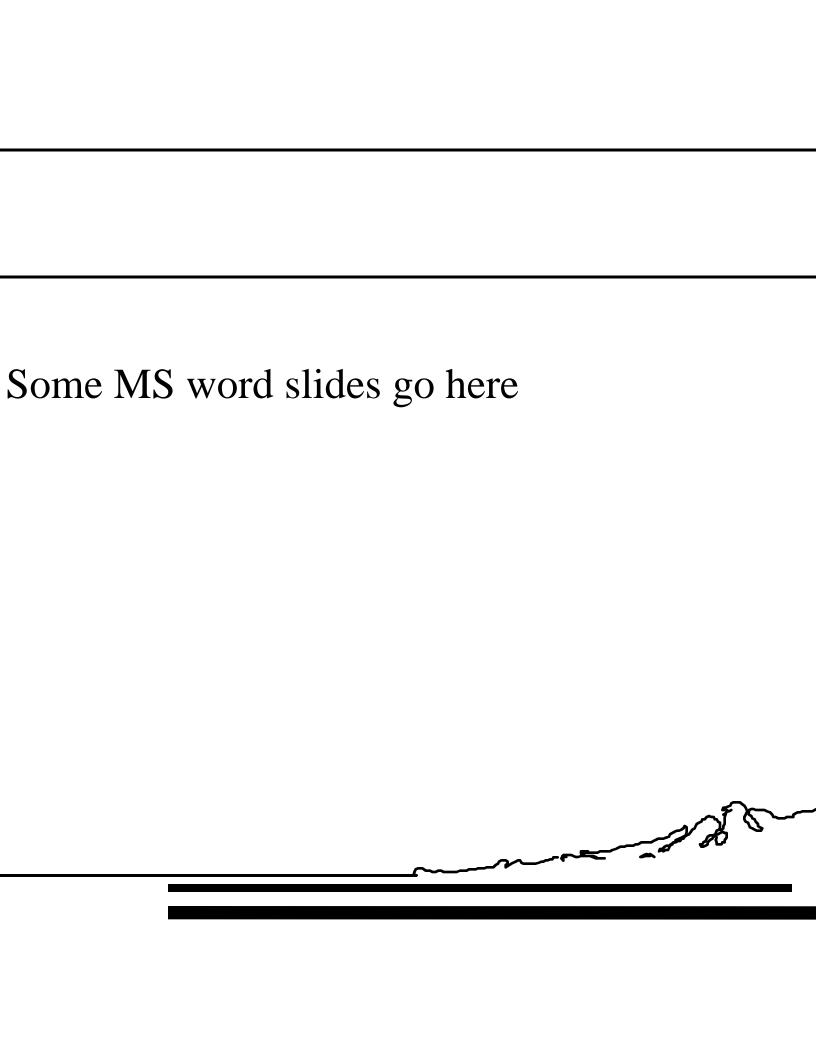
Determine Electron Density in Trap

- In-Situ Measurement
- Small Access Size

Stark Splitting of H lines with Static Fill of Hydrogen

Hydrogen Balmer Series

- H : $3p \rightarrow 2s n=3$ = 6563 Å (E = $1.892 eV = 1.5410^4 \text{ cm}^{-1}$)
- (H : = 4861 Å)



lectron Density Estimate (Photon Counti

Estimate electron density in anode volume by counting number of photons produced by electron impact ionization of neutral gas.

Use excitation peak of N_2^+ , 391.4nm

•S: Signal strength

•K: Monochromator, PMT, and fiber efficiency

•f: Optical fiber solid angle acceptance

•V: Viewed volume

•u: Electron velocity

•n0: Neutral gas density

•Q: Energy-dependent cross-section of process

Uncertainties - reflection of photons on anode walls

- electron energy distribution

Pressure (Torr)	Signal (s-1)	Density (cm ⁻³)	
2.1x10 ⁻⁵	270	1.0x10 ⁷	

Obstacles/Difficulties

High Voltage

- 100 kV Goal
- 75kV/35kV Operation

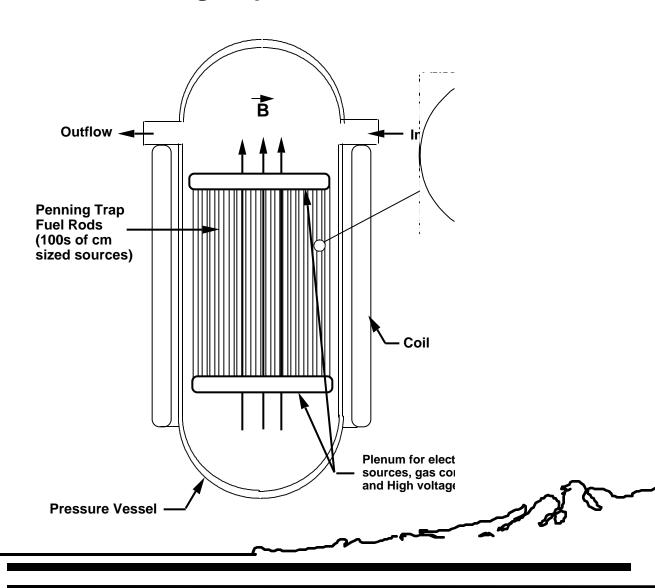
- Size/Access
 - Magnet Bore
 - HV Standoff
 - Diagnostics

Alignment

- Colinear
- Magnetic Field

Massively Modular Approach

Penning Trap Reactor Vessel



Summary

- •Ion focussing can be done with high Q (theory)
- •PFX-I addresses electron physics required for forming ion well
- Scaling path is to higher voltages, small size
- Massively modular reactor concept avoids material problems, removes insulators from high neutron flu provides heating power from direct conversion

Summary (cont.)

- •PFX-I has operated with electrons at low pressure and with gas added
- Diagnostics are electron dump and monochromate
- Spectroscopic system proven to detect molecular a ionic (molecular) lines
- Understanding electron confinement and distribut allows designing spherical well (tools are in hand)
- Our goal is to trap ions during the next few month

